The Effect of Tool Rotation on Structure and Mechanical Properties in Friction Stir Welding Of Aluminum AA5052

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Abstract: Welding of aluminum alloy materials is often used in the industrial world, including those engaged in shipping, aircraft, and others. The welding method used to bind aluminum materials is Friction Stir Welding (FSW). Friction Stir Welding (FSW) is a simple welding method, namely by utilizing the heat energy generated from the friction of the shoulder tool with the material being welded. This study aimed to determine the effect of tool rotation on the physical and mechanical properties of Friction Stir Welding of Aluminum AA5052. The material used in this study was aluminum with the series AA5052 as the primary material. The friction stir welding process was carried out using CnC milling with parameters of the tool rotation speed of 1000, 1200, and 1500 rpm and a feed rate of 25 mm/minute. Physical analysis was carried out using macro photo observations with a USB Digital Microscope and microstructural observations with optical metallography. Mechanical observations were carried out using tensile testing and hardness testing. The microstructure in the weld nugget area shows good results with fine and dense grains that occur due to the dynamic recrystallization process. The highest tensile strength is 102.49 MPa in the 1000 rpm parameter. This is due to the material mixing process and good heat transfer.

Keywords: Friction stir welding, Microstructure, Tensile stress.

1. INTRODUCTION

Welding is a method of binding two materials by melting some of the primary material with filler metal or without filler metal. The binding process is in a solid state because it takes place at a temperature before the melting point of the metal to be bound. One of the most widely used welding materials or metals is aluminum. Aluminum (Al) is a non-ferrous material. Aluminum has superior properties, including resistance to corrosion, a good conductor of heat and electricity, and light weight [1]. Aluminum is very much needed in the industrial world, but it still has problems with its weldability, thus requiring the right welding method. A welding method that can bind aluminum materials with good weldability results. Welding in the modern industrial world is developing rapidly, namely welding in industries engaged in transportation, shipping, railroads, automotive, and construction. All industrial welding engineering applications require quality welds [2, 3]. Welding Friction Stir Welding (FSW) is very simple, namely by utilizing the heat energy generated from the friction of the shoulder tool with the material being welded. The heat energy resulting from the friction turns into plastic materials. FSW standardized parameters, in terms of plate thickness, tool rotation speed, welding rate, tool dimensions, and material types currently do not exist [4], so the parameters of FSW are still being carried out by engineering the parameters of various welding trials. The FSW method has been used to bind various materials including aluminum alloy, copper alloy, steel, and various combinations of materials [5]. In fusion welding, porosity defects, low distortion and residual stress are always observed in the welding of aluminum materials [6]. Wang *et al*., have conducted a study on the effect of Friction Stir Welding (FSW) and Tungsten Inner Gas (TIG) welding processes on the fatigue properties of aluminum 5053 welded joints. The results show that the fatigue properties of FSW welded joints were better than those of TIG welded joints [7].

In welding with the FSW method, there is often a change in the physical and mechanical properties of the materials. A study conducted by Prabha *et al*., was to examine the effect of tool rotation speed on aluminum AA5083 with parameters of 900, 1120, 1400, and 1800 rpm. The results of the study indicate that the finer microstructure and the best tensile strength are found in the 1120 rpm parameter [8]. A study regarding the differences in pin tool profiles (square and pentagonal) on friction stir welding aluminum AA5052 has also been carried out by Kumar *et al*. [6]. The results show that the use of a pentagonal pin profile at a welding rate of 60 mm/m resulted in good quality welds when compared to other weldings. Friction stir welding method on aluminum materials with different series has also been studied by Ramana *et al*., using aluminum materials with the series AA5082 and AA6061 with parameters of welding rate of 15.20

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mm/minute and tool rotation speed of 1600 and 2600 rpm. The results show that Al 5082 welds have better mechanical properties obtained at a higher rpm and a high feed rate of 2600 rpm and 20 mm/minute respectively. At 20 mm/min higher welding, the ultimate strength is increased by 22.2% when the tool speed is increased to 2600 rpm, for similar Al 6061 welds, the welding rate and tool rotation speed do not significantly affect the tensile and hardness properties of the selected parameters [9].

From the description of some of the literature, Friction Stir Welding is very suitable for binding aluminum alloy, in order to produce good welds. Good weld results are affected (influenced) by tool rotation speed, welding rate, and others requiring studies on the effect of tool rotation on Friction Stir Welding to be still carried out extensively. Therefore, this study aimed to determine the effect of tool rotation on the physical and mechanical properties of Friction Stir Welding of Aluminum AA5052.

2. MATERIALS AND METHODS

The material used in this study was aluminum with the series AA5052, while the dimensions on the plate are 150 x 75 x 5 mm, as shown in Figure **1**. The chemical composition of the aluminum AA5052 material is shown in Table **1**. The material used as the FSW tool is medium carbon steel with an initial hardness value of 17 HRC. The material used as the FSW tool must have a high enough hardness so that when it is used for welding it does not experience wear and tear, thus the medium carbon steel was given heat treatment at a temperature of 900^{o}C and then followed by quenching. The final hardness value after given heat treatment increased to 52 HRC.

The type of pin profile used in FSW is Cylinder with a diameter and pin length of 5 mm, a shoulder diameter of 18 mm, and a shoulder length of 20 mm. This type of pin has also been used in a study conducted by Singh *et al.* [10], The design and pin profile are shown in Figure **2**. The parameters used in the FSW process were pin rotation speed of 1000, 1200, 1500 rpm and a feed rate of 25 mm/minute. These parameters refer to a study conducted by Rahmatian [11].

The machine used for the FSW process was a Universal Milling Machine with the FIRST MCV 300 brand. The temperature during Friction Stir Welding was measured using an infrared thermometer. The

Table 1: Chemical Composition of Aluminum AA5052

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
%	98.52	0.26	0.40	0.17	0.10	2.2-2.6	0.15-0.35	0.032	0.10

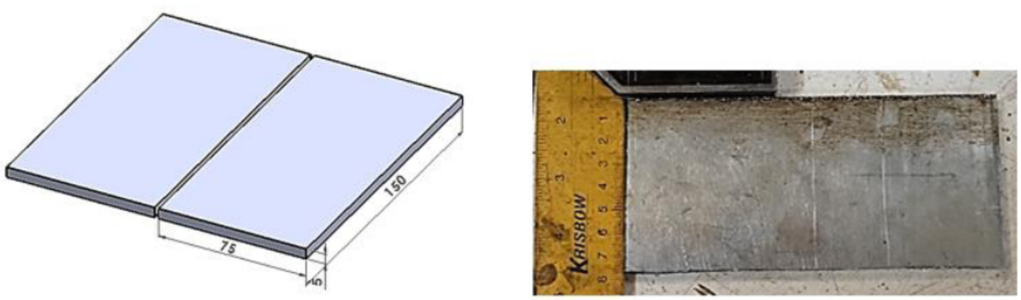

Figure 1: Dimensions of Aluminum AA5052 Materials.

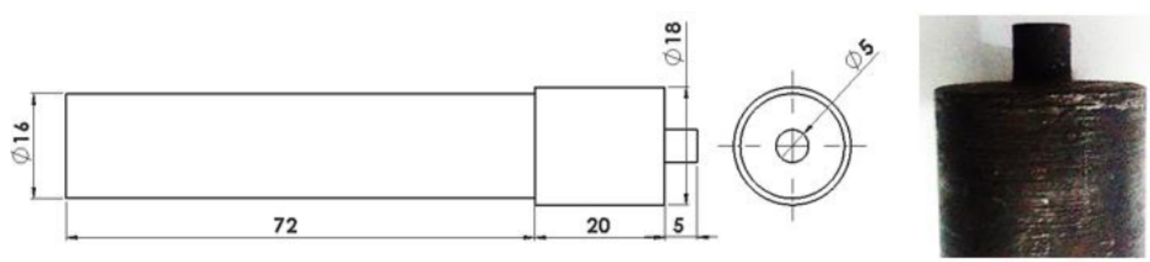

Figure 2: Pin designs and profiles.

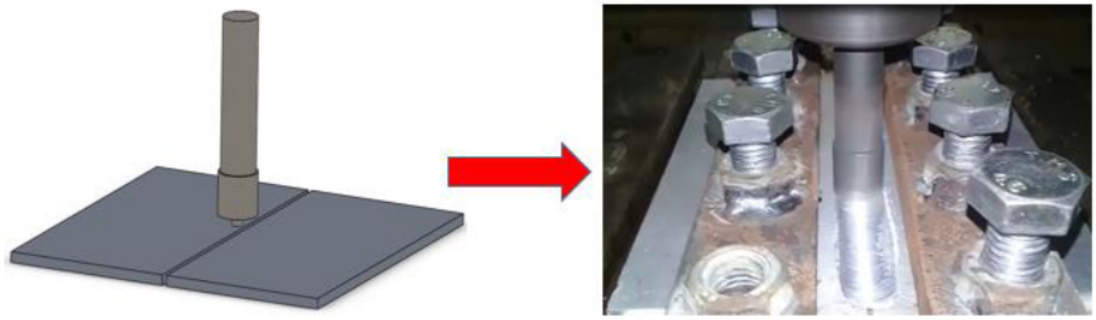

Figure 3: Friction Stir Welding Schematic.

FSW process began with preparing fittings as needed, including aluminum AA5052 materials, tool pin, backing plate, and milling clamp. The FSW tool was attached to the chuck and the aluminum materials were placed on the milling table. The tool was set at the position of the weld line which is the boundary between two plates of aluminum materials. The milling machine was run with reference to the parameters used by the researchers, namely tool rotation speed of 1000, 1200, 1500 rpm with a feed rate of 25 mm/minute. Penetration in the direction of the y axis was carried out automatically on a milling machine with a shoulder depth of 0.5 mm. When the tool penetrates into the aluminum materials, held for a few minutes and only then the tool was run on the weld line. Schematic welding is as shown in Figure **3**.

Microstructural morphological observations and tensile testing were taken transversely in the weld line/nugget zone, as shown in Figure **4**(**a**). Tensile testing specimens were made according to ASTM E8M standards, as shown in Figure **4**(**b**). Microstructure specimens were mounted using resin and sandpaper with sizes of 120, 220, 400, 800, 1000, 1500 and 2000. Etching on specimens used ASTM E407-07 No. 3 namely 2 mL HF, 5 mL HNO_3, 3 mL HCL, and 190 mL distilled water [12], then macro and micro observations were carried out.

3. RESULTS AND DISCUSSION

3.1. Macrostructure

Figure **5** shows the results of macro observations of welding results using the Friction Stir Welding method with parameters of 1000, 1200 and 1500 rpm with good average results. There is a slight defect with a fairly long flash type on FSW with a parameter of 1200 rpm. This happened because the shoulder tool was too deep during penetration. The welding defect and flash are in line with a study conducted by Aldanondo *et al.* [13]. The perforated defects in all welding results are where the tool pin comes out after being lifted up after welding. Welding defects can also occur due to various factors, including the length of the pin, tool rotation, so that the plastic material is unable to fill in the empty space. Welding defects can also occur due to various factors, including the length of the pin, tool rotation, so that the plastic material is unable to fill in the empty space [14].

The macro photo results of the cross-section results of Friction Stir Welding AA5052 in each parameter are shown in Figure **6**. The cross-section photo shows several parts. These parts include the areas of Weld Nuggets (WN), Thermomechanically Affected Zone (TMAZ), Heat Affected Zone (HAZ), and Base Metal

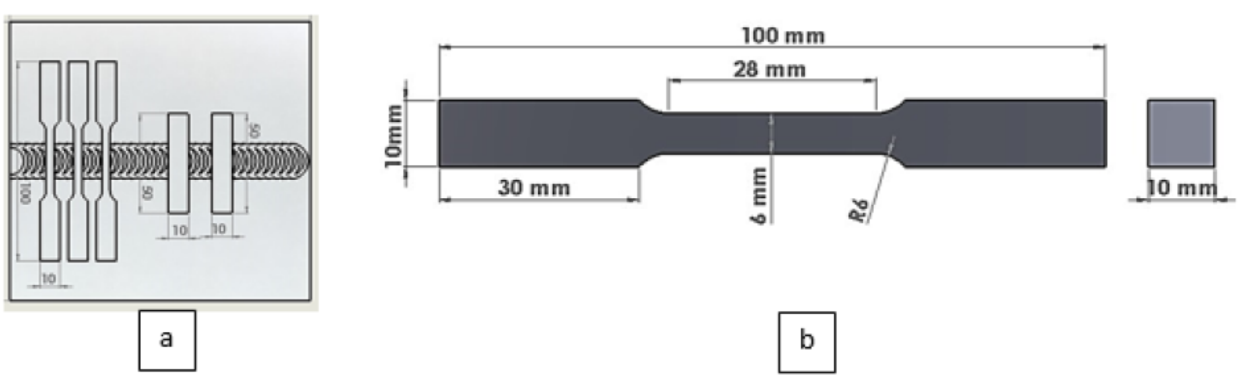

Figure 4: **a**). Sample area, **b**). Tensile Testing Specimen Standard (ASTM E8M).

Figure 5: Macro Photo, **a**). 1000rpm, **b**). 1200 rpm, **c**). 1500rpm.

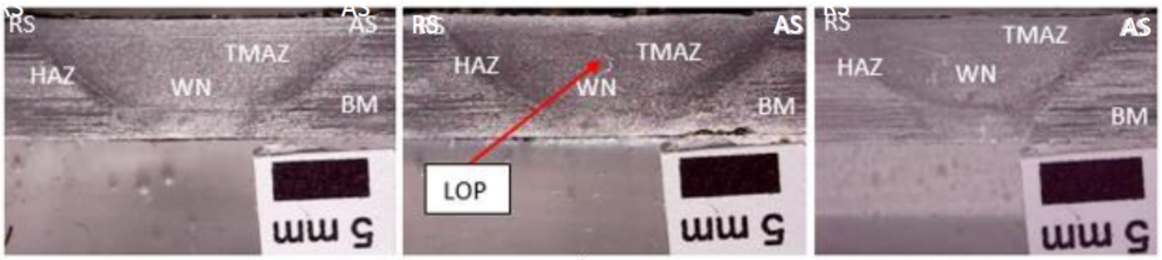

Figure 6: Cross Section, **a**). 1000rpm, **b**). 1200 rpm, **c**). 1500rpm.

(BM). These results were also conveyed in a study by Wang *et al*. [15]. The penetration tool in all parameters also shows the full thickness of the material [16]. In the cross-section, the welding parameter of 1200 rpm has a little Lack of Penetration (LoP) defect.

3.2. Micro Structure

Microstructural observations in the areaof Base Metal (BM) show that the size of the grain boundaries looks large when compared to the areas of WN, TMAZ or HAZ as shown in Figure **7**. The grain boundaries in the area of BM are filled with a number of Law Angle Boundaries (LABs) [15]. The microstructure in the area of BM is also seen to be elongated and the particle phase is parallel to the rolling direction of the materials [17].

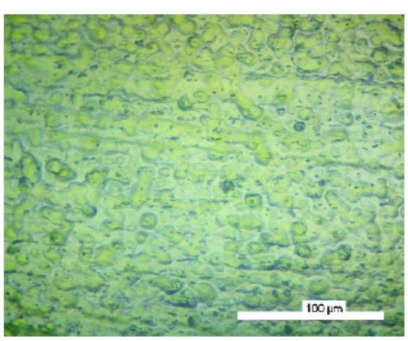

Figure 7: Micro Bass Metal Structure.

The microstructure in the area of Weld Nugget is seen as slightly smoother when compared to the TMAZ and HAZ areas. Fine grains in the areas of Weld Nugget and TMAZ occur due to plastic deformation and higher temperatures during the FSW process. These fine grains are also affected by frictional thermal cycles which cause the microstructure to undergo dynamic recrystallization and produce finer and more homogeneous grains [18]. This statement was also conveyed by Rajiv *et al,* that the microstructure of the weld nugget area is that Aluminum (Al) looks smooth, this is due to plastic deformation and high temperatures during the friction stir welding welding process which causes the material to recrystallize [19]. Kumbhar *et al*. [20] melaporkan bahwa evolusi struktur mikro reported that the evolution of the FSW microstructure was highly asymmetric, the evolution of the WZ microstructure was the strongest, followed by the backward side, and finally the forward side. There were no sub-grain boundaries in the WZ, Indicating that the LABs changed to High Angle Boundaries (HABs) with the migration of the original grain boundaries. On the other hand, coarser grains are shown in the microstructure of the Heat Affected Zone (HAZ). This is because the HAZ only experiences frictional heating without plastic deformation. In Figure **8**, it can be seen that the microstructure in the area of HAZ for parameters of the

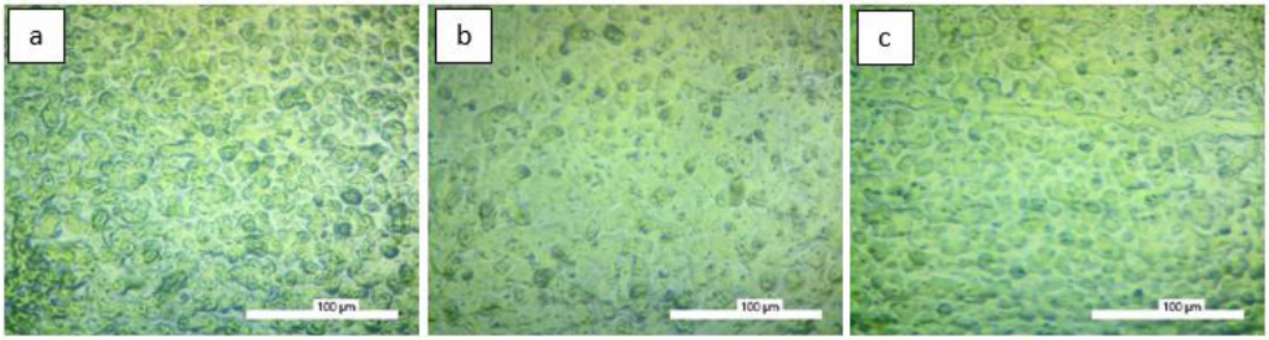

Figure 8: HAZ Microstructure, **a**). 1000 rpm, **b**). 1200 rpm, **c**). 1500 rpm.

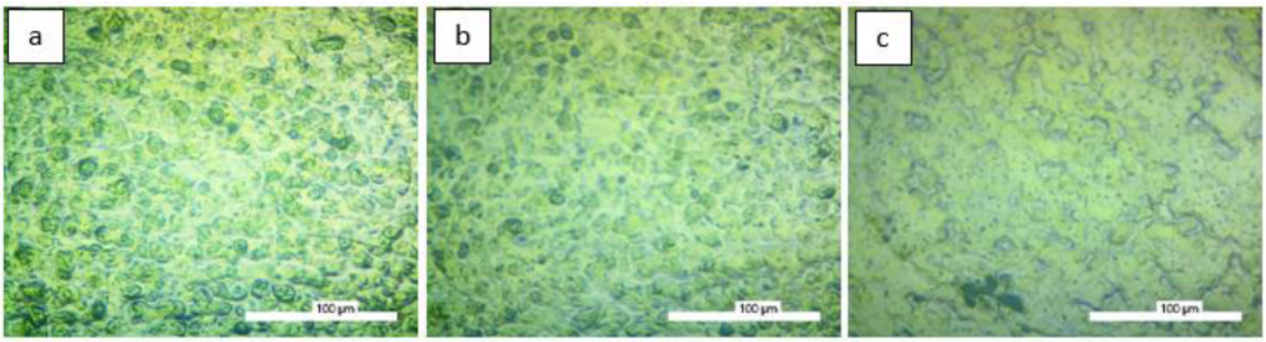

Figure 9: TMAZ Microstructure, **a**) 1000 rpm, **b**). 1200 rpm, **c**). 1500 rpm.

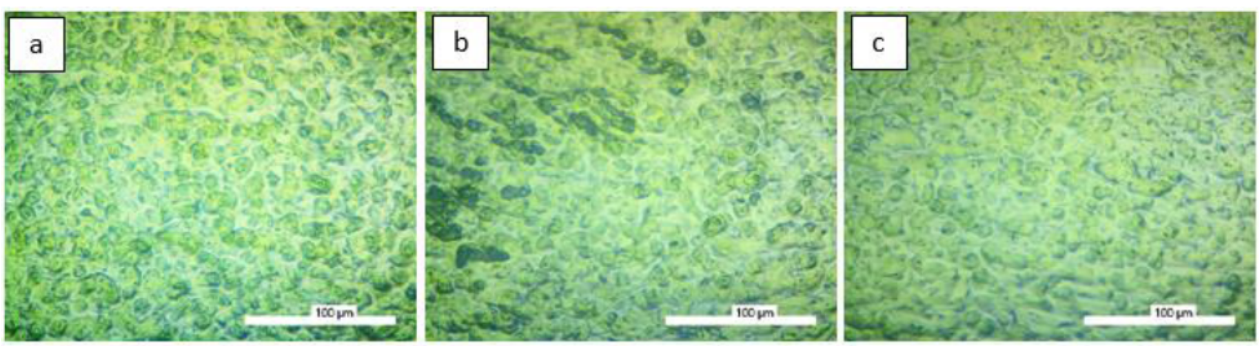

Figure 10: Weld Nugget Microstructure, **a**). 1000 rpm, **b**). 1200 rpm, **c**). 1500 rpm.

tool rotation speed of 1000, 1200, and 1500 rpm is almost similar this shows that the difference in tool rotation is not too influential.

Observing the average size of the microstructure in all research parameters. The average dimensions of the microstructure are presented in Figure **11**, showing the results of testing the average dimensions of the microstructures on all research materials. The base metal area has the highest average microstructure dimension of 19.1 µm, because the raw material area is not affected by the welding process. The average dimension of the microstructure of the HAZ area is 22.33µm, which occurs at 1200 rpm tool rotation parameter. As for the TMAZ area, the average dimension size is 20.16 µm which occurs at the 1500 rpm parameter. The size of the microstructure in the Weld Nugget (WN) area is 19.91 µm which occurs at 1000 rpm tool rotation parameters. Broadly speaking, the weld nugget area has the smallest and smoothest dimensions, this is because the area is experiencing dynamic recrystallization. Whereas the HAZ area has a large structural size, this shows that the area is only affected by heat and no other phenomena occur, so that the average dimension is larger than the other areas.

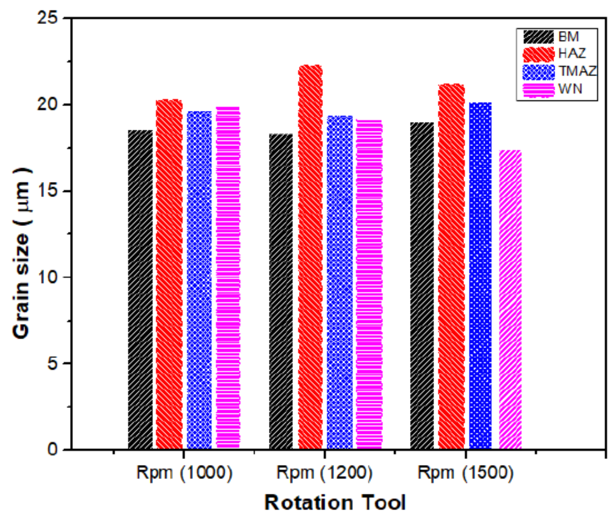

Figure 11: Grain size microstructure.

3.3. Hardness Test

Hardness testing was carried out using Rockwell scale B, with a load of 100 Kgf using an indenter with a diameter of 1/16 inch. Hardness values in the areas of Weld Nugget (WN), Thermomechanically Affected Zone (TMAZ), Heat Affected Zone (HAZ), and Base Metal (BM) are presented in Figure **12**. The X-axis (horizontal) shows the areas of WN, TMAZ, HAZ, and BM. Values -1, -2, -3 represent the results in the area of Retreating Side (RS), and values 1, 2, 3 represent the results in the area of Advancing Side (AS), while the center position value of 0 represents the area of Weld Nugget (WN). The highest hardness value is in the 1000 rpm parameter of the tool rotation, with a value of 55 HRB in the area of Weld Nugget and a value of 67 HRB in the area of TMAZ. It is observed that in almost all welds, the area of Weld Nugget has the highest hardness of 55 HRB compared to the area

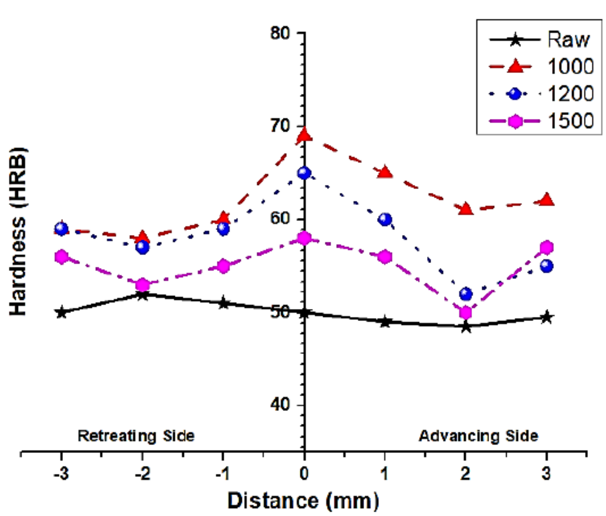

Figure 12: Rockwell Hardness.

of Base Metal. This is due to dynamic recrystallization. In the area of HAZ that is affected by the frictional heat generated, the grain particles are coarser and result in a decrease in the hardness value, when compared to WN. In TMAZ, the mechanical deformation by the tool shoulder results in an increase in hardness compared to HAZ. In the comparison of the areas of Advancing Side (AS) and Retreating Side (RS), AS has more hardness due to material flow [21].

3.4. Tensile Strength

Figure **13** shows the results of the tensile strength. The highest tensile strength results occur in the raw material, which is 111.73 MPa and the max stress is 123.43 MPa. In the Friction Stir Welding process with parameters of the tool rotation speed, the highest tensile strength is in the 1000 rpm parameter, namely 92.43 MPa with max stress of 102.49 MPa. This happened because the FSW welding results did not experience welding defects, as also shown in Figure **6**(**a**). Figure **6**(**a**) shows a smooth cross-section and soft micro grains. The decrease in tensile strength occurred in the 1200 rpm parameter FSW welding, namely 87.61 MPa with max stress of 96.89 MPa. The decrease in tensile strength in the 1200 rpm parameter occurred due to a softening effect on the area of Weld Nugget and also due to the occurrence of welding defects [22].

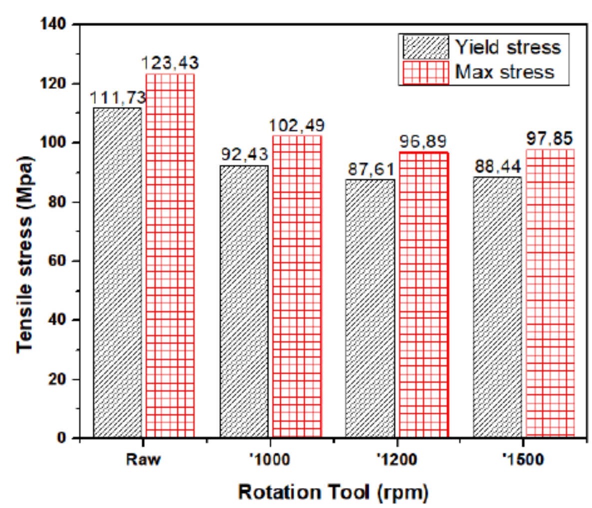

Figure 13: a). Tensile Stress.

4. CONCLUSION

Macro photo observation shows that there is a slight welding defect in the welding parameter of 1200 rpm. The microstructure in the area of Weld Nugget has small and soft grains. This is due to dynamic and homogeneous recrystallization. This is different when compared to the microstructure in the areas of TMAZ, HAZ, and Base metal which have large and elongated grains. The highest hardness value is in the 1000 rpm tool rotation parameter, with a value of 55 HRB in the area of Weld Nugget and a value of 67 HRB in the area of TMAZ. It is observed that in almost all welds, the area of Weld Nugget has the highest hardness of 55 HRB compared to the area of Base Metal. This is due to dynamic recrystallization. The highest tensile strength is in the 1000 rpm parameter, namely 92.43 MPa with a max stress of 102.49 MPa.

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